

## **Lateral Mixing and AESOP**

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### **LONG-TERM GOALS**

I seek to understand the processes controlling lateral mixing in the ocean, particularly at the submesoscale, i.e. 100m-20km.

### **OBJECTIVES**

Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the  $O(1)km$  -  $O(10)km$  resolution scale. We aim to determine the physical limitations of subgrid parameterization on these scales. These projects address the following questions:

- What physics govern horizontal and vertical mixing in the presence of horizontal variability on the 1-10 km scale?
- What is the relative importance of horizontal and vertical mixing in determining the structure of the boundary layer?
- What physics should be included to improve parameterizations?

### **APPROACH**

These projects continue the analysis of the 2006 and 2007 AESOP and fund preparations for the 2011 and 2012 Lateral Mixing experiments. During AESOP, Lee and D'Asaro pioneered an innovative approach to measuring submesoscale structure in strong fronts. An adaptive measurement program employed acoustically-tracked, neutrally buoyant Lagrangian floats and a towed, undulating profiler to investigate the relative importance of vertical and horizontal mixing in governing boundary layer structure in the presence of  $O(1\text{ km})$  scale horizontal variability.

Remotely sensed sea surface temperature and ocean color, combined with rapid, high-resolution towed surveys and model results guide float deployments to key locations within fronts. Synoptic, high-resolution surveys followed Lagrangian float drifts to characterize three-dimensional variability within the span of a model grid points. Acoustic tracking allowed towed surveys to follow floats and geolocated all observational assets for later analysis. Measurements characterized boundary layer turbulence and facilitated detailed separation of vertical and horizontal processes. These

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measurements were specifically designed to allow direct comparison with Large Eddy Simulations of the measurements by Ramsey Harcourt and thus have direct application to assessing regional model subgrid parameterizations.

## **WORK COMPLETED**

The first of two cruises associated with the AESOP effort took place from R/V Roger Revelle, 16 July – 8 August 2006 off the California coast. The best data was taken for 3 days along a north-south front. We call this AESOP I. The second, 2007 field effort focused on the strong fronts and submesoscale features associated with the Kuroshio extension. The best data was taken in the region of strong confluence and frontogenesis as the Kuroshio/Oyashio front is formed off Japan. We call this AESOP II.

A manuscript describing the AESOP-II analysis is complete and will be submitted shortly. We have worked with Leif Thomas to make quantitative comparisons between our data and recent theoretical predictions on the structure of boundary layers in fronts.

The basic analysis of AESOP-I is nearly complete. Andre Shcherbina has combined float, shipboard ADCP and Triaxus scalar and velocity data to construct time varying fields of velocity, temperature and salinity in a volume approximately 5 km across following the float. From these, the budgets of heat and salt and time series of potential vorticity have been constructed. We are working with Leif Thomas to interpret these in terms of the expected evolution of a front undergoing frontogenesis, instability and dispersion.

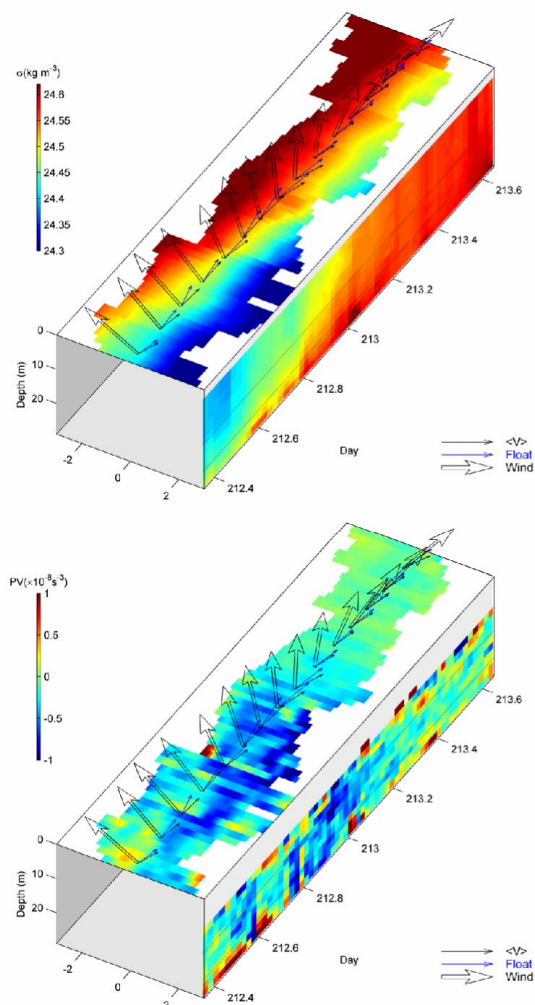
Experimental efforts in the Lateral Mixing DRI will continue the work begun during AESOP using similar techniques. Work during 2010 was mostly planning, although some design work on my component of the program has begun. I participated in DRI planning meetings in December 2009, February 2010 and July 2010.

## **RESULTS**

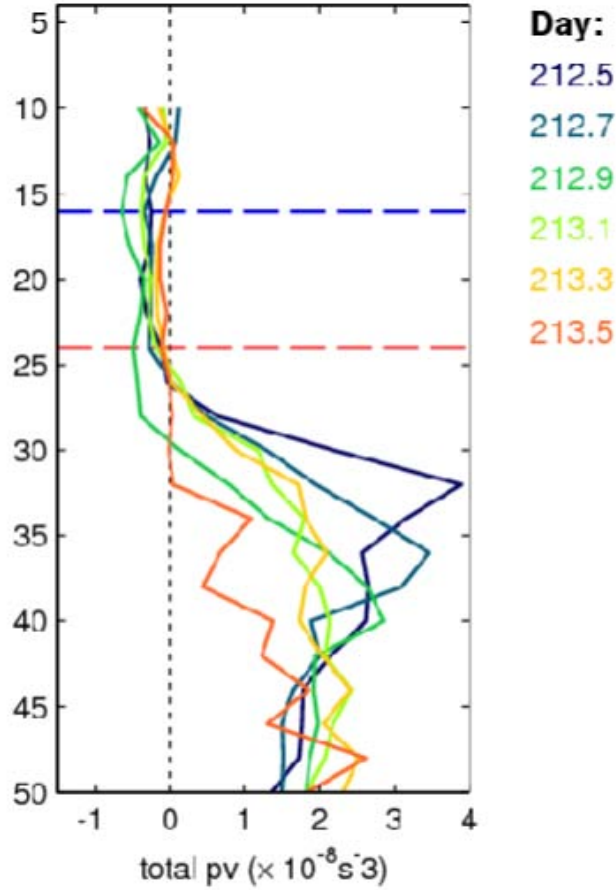
The reanalysis of the AESOP-II data has focused on a small region of very strong shear and enhanced boundary layer mixing, which we call the “Sharpest Front.” This region is remarkable because of the anomalously high turbulence levels. We have now quantified the turbulence level and find it consistent with recent numerical simulations by Leif Thomas, John Taylor and Raf Ferrari. As we say in our paper:

*The mechanisms by which the ocean circulation is dissipated are poorly understood. Here, we present experimental evidence suggesting that significant dissipation occurs at fronts. At a 1-km-wide front within the Kuroshio, the potential vorticity was negative and the rate of energy dissipation within the upper boundary layer was enhanced by 10-20 times. The data quantitatively supports the hypothesis that winds aligned with the frontal velocity catalyzed the release of energy from the front by driving the potential vorticity negative thereby causing symmetric instability and excess dissipation. Integrated over the world's oceans, it is estimated that 5-15% of the total wind-work on the circulation could be dissipated at fronts by this mechanism.*

For AESOP-I Fig. 1 and Fig. 2 illustrate our detailed volumetric analysis and show the evolution of potential density and potential vorticity in the analysis volume.



**Fig. 1. Three-dimensional evolution of (top) potential density and (bottom) potential vorticity (PV) in a volume surrounding the Lagrangian float during AESOP-I. A density front is apparent throughout the observations with the float at or near the front. The wind is increasingly down-front through the record. Negative PV is evident at the front for the first half of the observations.**



**Fig. 2. Profiles of potential vorticity as a function of time in the frontal region. PV is uniformly negative through the boundary layer for the first half of the measurements; then becomes zero. PV is strongly positive in the underlying stratification.**

We hypothesize the following scenario. Initially, the float is on the downwelling side of the front so that the vertical velocity is stretching, convergent and therefore frontogenic. The downfront winds increase mixed layer depth and density through cross-frontal Ekman flux and drives the PV negative. Near the middle of the record, the float is advected across the front into a region of reduced confluence. Here sunshine and diffusion cause a net decrease in PV until the end of the measurements. This interpretation is consistent with our observations of these quantities and the larger-scale, omega-equation analysis of this region by E.Pallas-Sanz, T. M. S. Johnston, and D. L. Rudnick using a larger scale survey at the same time as our measurements.

## IMPACT/APPLICATIONS

Our results suggest that a boundary layer parameterization that includes both the effects of atmospheric forcing and lateral gradients is possible and could be implemented in regional models.